Development and Optimization of Multi Point Cutting Tool from Recycled Steel using Agrowaste as Case Hardening

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Abstract. This research created a cutting tool made of recycled steel, palm kernel shell and alloy additives. Scrapped crankshaft and rod (100 kg) containing 0.5607% carbon were charged into an electric induction furnace with a maximum temperature of 3000°C for melting. Before and after melting, the chemical composition of the charged components was determined using a UV-VIS spectrometer. Alloy additives were added in order to meet the carbon and other elements content of high Speed Steel materials. Samples were pulverized with carbon and heat treated. The performance of developed tool was evaluated using wear rate, toughness and micro structural analysis respectively. High proportion of carbide and strengthened martensite were obtained from the microstructure. The tool's surface hardness and micro-hardness were 76.8 and 47.9 HB, respectively, while that of the control sample's were 76.3 and 46.1 HB. Minimum wear rate and toughness of the 1ool were $1095x10^{-8}m^2/N$ and 15.01 J, while those of the control sample were $1.127x10^{-8}$ Cm^2/N and 17 J respectively.

1 Introduction

Multiple-point cutting tools are mechanical tools that are used to shape materials by eliminating extra material from the work piece [1-2]. The tool's cutting blades are positioned such that they make simultaneous contact with the work piece, resulting in many chips in one pass. multiple point cutting tool design can vary based on the application, material being machined, and intended output [3-4]. Multiple point cutting tools have been used to make complicated components with great precision and accuracy in sectors such as automotive, aerospace, and medicine [5]. These tools are favored over single-point cutting tools because they remove material more quickly, resulting in higher productivity and reduced machining time. One of the most serious issues with multiple point cutting tools is heat production during machining, which can result in premature tool wear and failure [6-8]. Furthermore,

chip evacuation can be difficult when cutting materials that create lengthy and stringy chips, resulting in chip accumulation and work piece damage. Another consideration is the expense of producing and maintaining multiple point cutting tools, which can be more expensive than single-point cutting tool [9]. Recent industrial growth has resulted in a sharp increase in the amount of wastes produced. One of such wastes is agricultural wastes [10-12]. This wastes amount to a menace in the society and has resulted in many studies to discover how these agro wastes can be recycled [11]. Such wastes include wastes from rice husk, palm kernel shell, banana leaves and stump, egg shell e.t.c [12]. In this study, a mild steel bar was case hardened with selected agro wastes to determine the effectiveness of the cutting tool.

2 Materials and methods

2.1 Materials

The materials employed for this study include mild steel rod, Palm kernel shell (pulverized carbon), coconut shell and oil. Figure 1.

Fig. 1. Agrowastes used for study (a) Palm kernel shell (PKS) (b) Pulverized PKS (c) Coconut shell (d) Pulverized coconut shell.

2.2 Equipment

The equipment used for the study includes a Muffle electric furnace (manufactured by Keith Incoporation in the U.S.A.) with model number KB3 and a capacity of 1500ºC. A Milling Machine was employed for pulverizing the wastes, a microscope for characterization, a Brinell Hardness tester, a Micro hardness tester - LECO Incorporation U.S.A. LM700AT-FM7696 and a Digital weigh scale- Camry Godmarc India CAP .260 Ibs GRAD .2 Ib.

2.3 Experimental procedure

2.3.1 Cutting Tool Design

The cutting tool was first designed using solid works to model the appearance and other details of the tool Figure 2a. The modeling was carried out using solid works software version 2020. The chosen material for this is mild steel. The process for the cutting tool development is as displayed in the flow chart in Figure 2b.

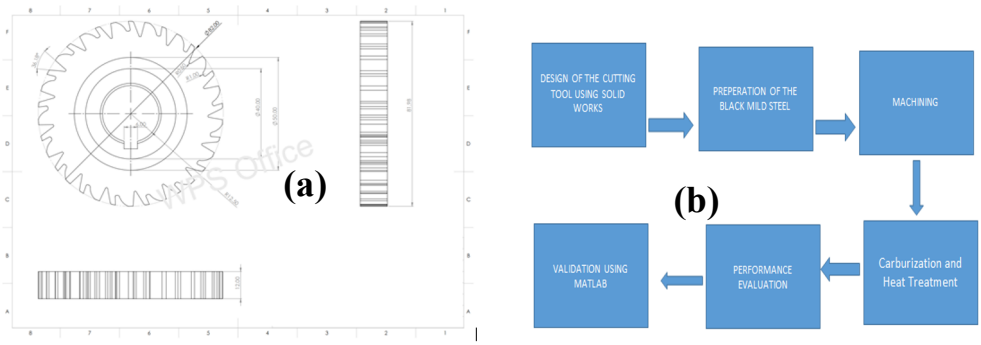

Fig. 2. (a) Cutting tool design (b) Process flowchart

2.3.2 Design Calculations

The required parameters which are needed for the appropriate modelling and simulation of the gear are measured in millimetres and they are number of gear teeth (N) and Reference diameter (D). The module of the gear cutter was determined using equation 1.

$$Module\ (m) = \frac{D}{T} \qquad (1)$$

Where D represents reference diameter ad T represents number of gear teeth.

The pitch of the tooth, tooth thickness, tip diameter, root diameter, tooth depth and finally tip and root clearance were determined using equations 2-6

$$Pitch\ (p_c) = \pi m \qquad (2)$$
$$P_b = p_c \cos \varphi \qquad (3)$$
$$Tooth\ thickness\ (s) = \frac{Pitch}{2} = \pi m \qquad (4)$$
$$Tip\ diameter\ (d_a) = D + 2\ m \qquad (5)$$
$$Root\ diameter\ (d_f) = D - 2.5\ m \qquad (6)$$
$$Tooth\ depth = Addendum + Dedendum = a + d \qquad (7)$$
$$Tip\ and\ Root\ Clearance\ (c) = d - a \qquad (8)$$

Where Where, P_b is the base pitch, φ is pressure angle, a is the Addendum and d represents the Dedendum.

2.3.2 Preparation of Mild Steel

The mild steel sample used for the development of the cutting tool followed the following process.

(i) Machining:

A cutting tool was used to machine the mild steel rod down to the specified diameter of 115.45mm using a milling machine to produce the desired spur gear.

(ii) Carburization

The prepared two samples each of sizes will be inserted in the pulverized egg and coconut shell. To prevent CO from escaping and undesired furnace gas from entering the steel box during heating, the carburizer was weighed and packed within steel boxes with a density of 700g/cm3 and firmly covered with powdered egg and coconut shell cover. The muffle furnace was loaded one prepared box at a time, and the operating temperature within the furnace was set to the appropriate temperature (800, 850, 900, and 950 °C) for each stage, before charging the loaded steel box into the muffle furnace one by one. Each sample will be carburized in proportion to the specified holding time and temperature.

(iii) Heat Treatment

Two pieces each of the spur gears were charged into the treatment muffle furnace at 1500ºC and the pieces were annealed (heated up to 900°C at the rate 90ºC per hour and held for 2 hours), hardened (heated up to 900°C at 100°C / hr for 9 hrs and force-cooled from 900ºC with oil as quenching medium), normalized (heated up to 900ºC at 100ºC / hr for 9 hrs and it will then naturally cool in air from 900ºC) and tempered (heated up to 400ºC at 100ºc/hr for 4hrs and it will then naturally cool with air from 400ºC) Figure 3c&d.

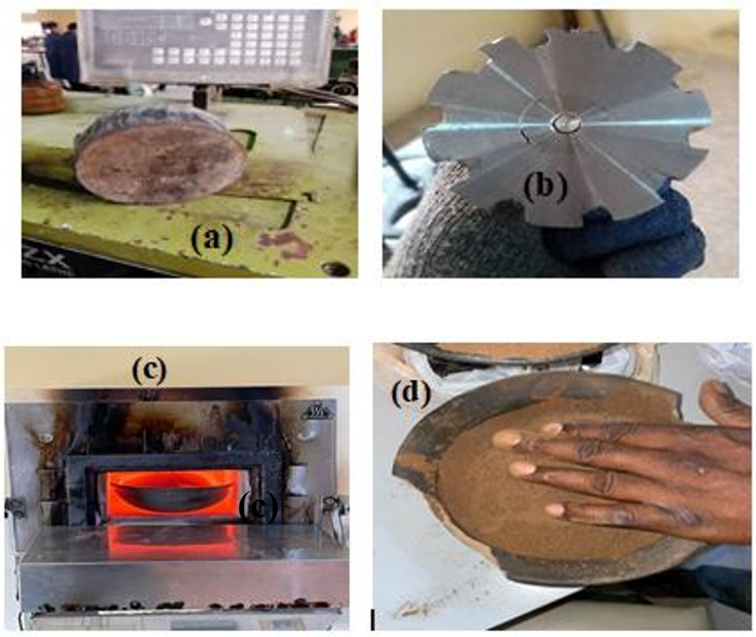

Fig. 3. Steel sample & Heat treatment process (a) raw steel sample (b) Multi point tool (c) Furnace during hardening (d) cooling during annealing

2.2 Performance Evaluation

After the spur gear undergoes the carburizing and various heat treatment processes, a number of tests are carried out in order to determine toughness, wear resistance and other key factors affecting its viability. These tests include hardness test, wear test and a microstructural analysis. Surface hardness test will be carried out using Brinell (H_B) hardness tester which was determined on carburized samples of mild steel at temperatures of 800, 850, 900, and 950 °C. The test was repeated three times for each sample, and the average of all samples was used to determine the observed results in each case. The Rotopol -V and Impact tester were used for the test. The wear volume of each sample was assessed after 10 minutes of cutting. The internal makeup of the spur gear constructed and the control was studied to see the influence of the heat treatment on cutting tool. Finally, the developed cutting tool samples were used to for turning operation on a milling machine to cut low carbon steel so as to measure the time of cut, length of cut, depth of cut at different cutting speeds and feed rate. This was done to evaluate the performance of the developed samples.

3 Results and discussion

3.1 EDX / Hardness Test Result

The hardness test results for the carbonized cutting tool using the Brinell hardness tester are displayed in the tables below. These illustrate the degree of hardness in the cutting tool's surface, as well as the surface hardness values in the case of carbonized samples. Figure 5 show the EDX for the control sample before passing through the caburization process. The main property that the caburization process improved on was the carbon content which in turn improved the hardness of the various samples as shown in Table 1.

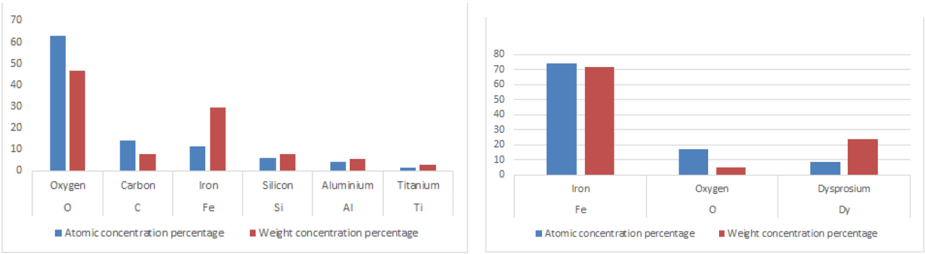

Fig. 4. EDX for samples (a) control (b) heat treated sample

Table 1: Summary of Brinell hardness test

SAMPLE	Caburization temperature (°C)	Holding Time (mins)	Agro-Waste Percentage (%)	Brinell Hardness number
A	900	120	50% CS, 50% PKS	1.85×10^{-8}
B	900	120	100% PKS	1.55×10^{-8}
C	900	120	100% CS	1.85×10^{-8}
D	900	120	70% CS, 30% PKS	1.68×10^{-8}
E	900	120	30% CS, 70% PKS	2.39×10^{-8}

The highest hardness value was observed for Sample E which had a composition of 30% CS, 70% PKS with a Brinell hardness value of $2.39x10^{-8}$ (Table 1). This was even better than pure samples (100%) of PKS and CS both of which had Brinell hardness values of $1.55x10^{-8}$ and $1.85x10^{-8}$ respectively. This demonstrates the fact that the produced sample composition having performed optimally in hardness value is a preferred sample composition to use as cutting tool.

3.2 Measurement of wear volume and wear rate wear resistance

The result of test carried out on the treated cutting tool to measure its wear volume, wear rate and wear resistance are shown in Table 2. The highest wear volume value of 0.0096 cm^3 was recorded for Sample E. This is understandable since Sample E had the lowest wear rate and highest resistance of 5.476×10^{-10} and 5.83×10^{9} respectively. This further proves that the carburization of Sample E had drastically increased its hardness value resulting in increased wear resistance. This makes Sample E the preferred composition for the mixture of PKS and CS for the case hardening of the developed mild steel cutting tool.

Table 2: Summary of Wear Volume, Wear Rate, Wear Resistance

S/N	Sample(s)	Wear Volume (cm^3)	Wear Rate (cm^2)	Wear Resistance (cm^2)
1	A	0.00103	2.190×10^{-8}	4.57×10^{7}
2	B	0.00258	5.476×10^{-9}	1.83×10^{8}
3	C	0.00994	2.108×10^{-8}	4.74×10^{7}
4	D	0.00181	3.833×10^{-8}	2.61×10^{7}
5	E	0.00096	5.476×10^{-10}	5.83×10^{9}

3.3 Performance Evaluation of developed samples via milling.

The experimental result from the turning process carried out using the developed samples of cutting tool is presented in Table 3. On a low carbon steel work piece with a diameter of 25mm, the responses measured were time of cut at 50 m/mm, spindle speed at 380Rev/min, feed rate at 19.00mm/min, and depth of cut at 2mm. The highest time of cut (2.97 mins) was recorded while turning was done with Sample E, while the lowest time of cut (1.44 mins) was recorded with Sample B. All 3 other samples performed averagely between both extremes. Hence, Sample E was the preferred mix as its performance was better than all 4 other samples.

Table 3: Machining mild steel to determine time of cut

S/N	Sample(s)	Length of cut (mm)	Time of Cut (mins)
1	A	50	1.50
2	B	50	1.44
3	C	50	1.49
4	D	50	1.58
5	E	50	2.97

4 Conclusion

The development of a multi point type cutting tool from recycled steel by employing PKS and CS as case-hardening materials has been attempted. Results show that a mixture of 30% CS, 70% PKS (Sample E) was the preferred mix as this carburized mild steel mix demonstrated enhanced hardness and wear resistance values, as well as improved toughness performance during cutting operations. It was also preferred because the wear rate and volume of the cutting tool reduced resulting in better performance with an extended time of cut of 2.97 minutes which was longer than that returned by all other samples. Hence, a mixture of 30% CS, 70% PKS is recommended for case hardening cutting tools developed from mild steel.

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